

# EE2019: Analog Systems and Lab

## Course summary

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# RLC circuit analysis

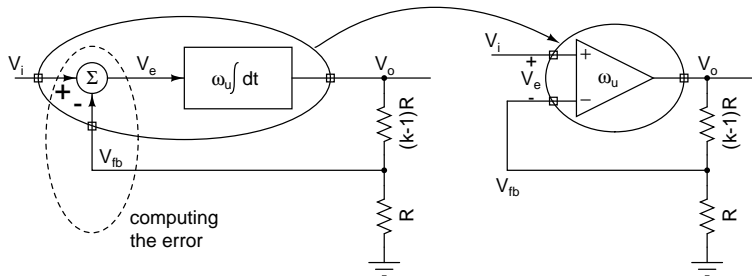
## Time domain

- Step response
- Initial/final values and time-constants

## Frequency domain

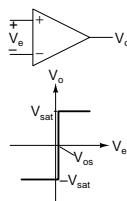
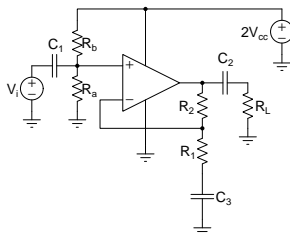
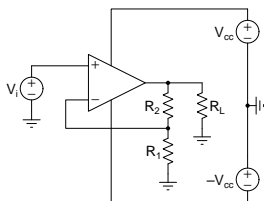
- Transfer function, poles and zeros
- Sinusoidal steady-state response; Bode plots

# Negative feedback amplifier and the opamp



- Infinite gain model
- Virtual short with negative feedback
- Finding opamp signs for negative feedback

# Biasing opamp circuits



- Opamp saturation and offset
- Single and dual supply operation
- AC coupling

# Opamp characteristics



August 2000

## LF147/LF347

### Wide Bandwidth Quad JFET Input Operational Amplifiers

#### General Description

The LF147 is a low cost, high speed quad JFET input operational amplifier with an internally trimmed input offset voltage (BI-FET II™ technology). The device requires a low

#### Features

- Internally trimmed offset voltage: 5 mV max
- Low input bias current: 50 pA
- Low input noise current: 0.01 pA/√Hz

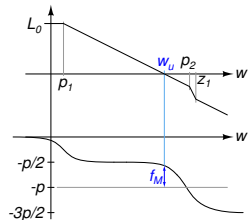
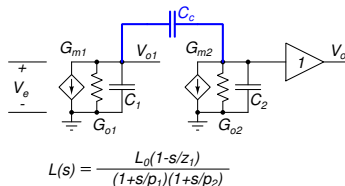
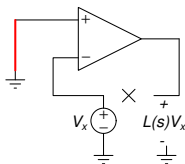
#### DC Electrical Characteristics (Note 7)

Symbol	Parameter	Conditions	LF147			LF347B			LF347			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
$V_{OS}$	Input Offset Voltage	$R_S=10\text{ k}\Omega$ , $T_A=25^\circ\text{C}$ Over Temperature		1	5		3	5		5	10	mV
$\Delta V_{OS}/\Delta T$	Average TC of Input Offset Voltage	$R_S=10\text{ k}\Omega$		10			10			10		$\mu\text{V}/^\circ\text{C}$
$I_{OS}$	Input Offset Current	$T_J=25^\circ\text{C}$ , (Notes 7, 8) Over Temperature		25	100		25	100		25	100	pA
$I_B$	Input Bias Current	$T_J=25^\circ\text{C}$ , (Notes 7, 8) Over Temperature		50	200		50	200		50	200	pA
$R_{IN}$	Input Resistance	$T_J=25^\circ\text{C}$		$10^{12}$			$10^{12}$			$10^{12}$		$\Omega$
$A_{VOL}$	Large Signal Voltage Gain	$V_S=\pm 15\text{V}$ , $T_A=25^\circ\text{C}$ $V_O=\pm 10\text{V}$ , $R_L=2\text{ k}\Omega$ Over Temperature	50	100		50	100		25	100		V/mV
$V_O$	Output Voltage Swing	$V_S=\pm 15\text{V}$ , $R_L=10\text{ k}\Omega$	$\pm 12$	$\pm 13.5$		$\pm 12$	$\pm 13.5$		$\pm 12$	$\pm 13.5$		V
$V_{CM}$	Input Common-Mode Voltage Range	$V_S=\pm 15\text{V}$	$\pm 11$	$\pm 15$		$\pm 11$	$\pm 15$		$\pm 11$	$\pm 15$		V
CMRR	Common-Mode Rejection Ratio	$R_S\leq 10\text{ k}\Omega$	80	100		80	100		70	100		dB
PSRR	Supply Voltage Rejection Ratio	(Note 9)	80	100		80	100		70	100		dB
$I_S$	Supply Current			7.2	11		7.2	11		7.2	11	mA

Source: [www.ti.com/lit/ds/symlink/lf147.pdf](http://www.ti.com/lit/ds/symlink/lf147.pdf)

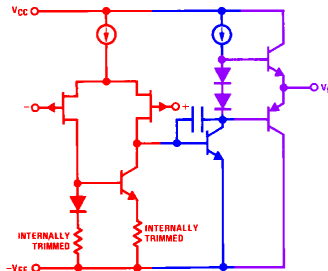
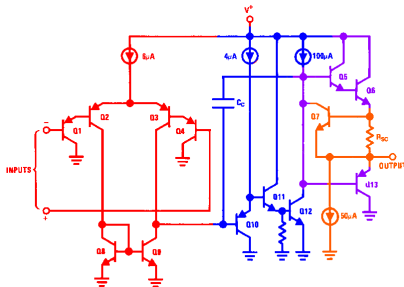


# Stability of negative feedback circuits

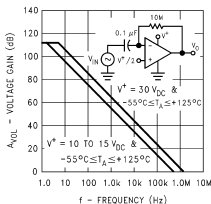


- Stability criterion—Loop gain and phase margin
- Dominant pole compensation
- 2-stage Miller compensated opamp

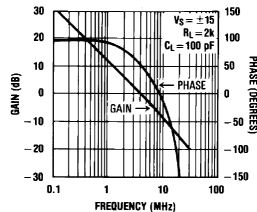
# Opamp examples: LM324, LF147



Open Loop Frequency Response

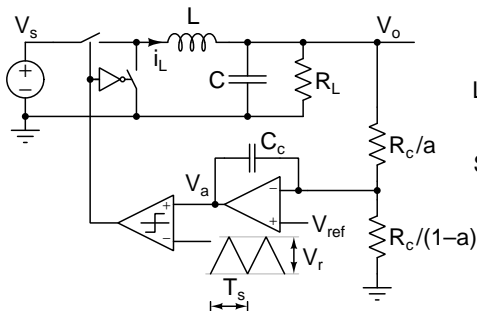


Bode Plot



Source: [www.ti.com/lit/gpn/lm124](http://www.ti.com/lit/gpn/lm124), [www.ti.com/lit/ds/symlink/lf147.pdf](http://www.ti.com/lit/ds/symlink/lf147.pdf)

# DC-DC converters



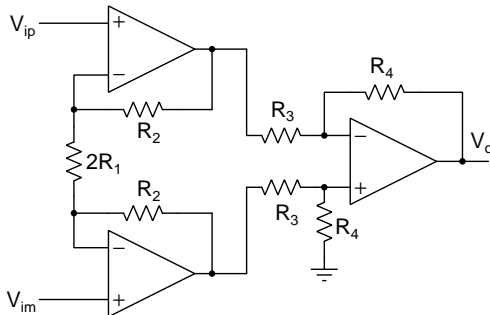
$$L(s) = \frac{a}{sC_cR_c} \frac{V_s}{V_r} \frac{1}{s^2LC + sL/R + 1}$$

Steady state  $V_o = V_{ref}/a$

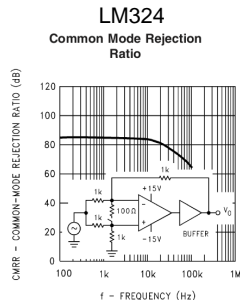
- DC-DC buck converter
- Average model from duty cycle to the output
- Voltage regulation loop and its stability



# Instrumentation amplifier



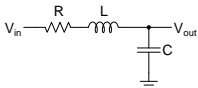
- Instrumentation amplifier
- Common-mode and differential mode signals
- Common-mode rejection ratio (CMRR)



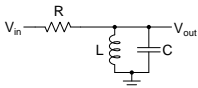
Source: [www.ti.com/lit/gpn/lm124](http://www.ti.com/lit/gpn/lm124)

- Passive RLC filters
- State-variable filter: Emulate equations of RLC filters using integrators
- Sallen-Key, Rauch filters, . . .

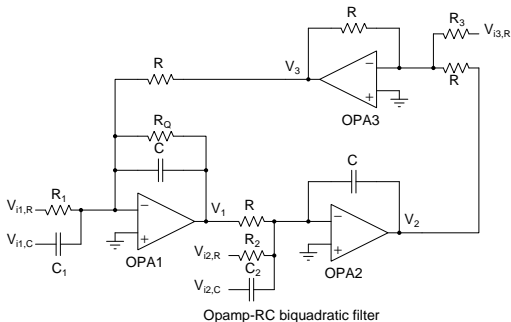
# Filters



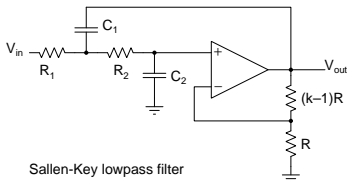
Series RLC lowpass filter



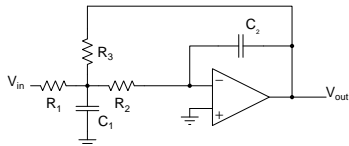
Parallel RLC bandpass filter



Opamp-RC biquadratic filter

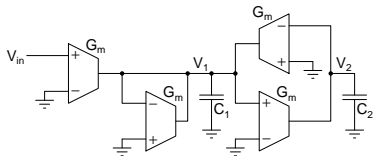


Sallen-Key lowpass filter

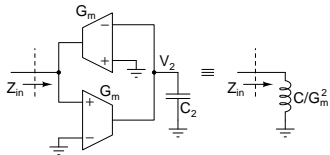


Rauch lowpass filter

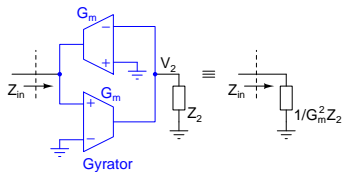
# Filters



$G_m$ -C second-order filter



Inductor emulation

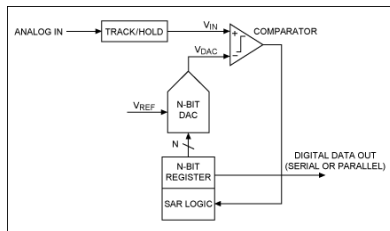


Gyrator

# Oscillators

- LC resonant network compensated by a negative conductance
- Double integrator oscillator, Wien bridge oscillator
- Schmitt trigger oscillator

# Data converters



## Sampling

- Track and Hold (T/H), Sample and Hold (S/H)

## Analog-to-digital conversion

- Flash ADC for high speed and low resolution
- SAR ADC for low speed and high resolution

## Digital-to-analog conversion

- Resistor DAC: Resistor string, R-2R, binary weighted
- Binary weighted capacitor DAC (Suited for SAR ADCs)

Source: [www.maximintegrated.com/en/app-notes/index.mvp/id/1080](http://www.maximintegrated.com/en/app-notes/index.mvp/id/1080)

# Acknowledgments: Army of TAs